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Analyzing the Efficiency of Increasing Suitable Habitat Area for *Paridae* by Roof Greening Method Based on Building Type: Case Study of Suwon City, Republic of Korea

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Owing to the proliferation of people in cities worldwide, the size of urban green areas has decreased along with biodiversity. Suwon City, a highly populated area adjacent to Seoul, the capital of the Republic of Korea, and the subject of this study, has been making significant efforts to prevent such a decrease in biodiversity. In this study, we aim to develop a suitable scenario for roof greening in Suwon City, analyze how the efficiency of increasing the suitable habitat area of the *Paridae* bird changes with the scenario, and propose the most efficient roof greening plan. For the development and application of this plan, public, commercial, and residential buildings were selected as target spaces to which roof greening was applied. Then, the appropriate roof greening area was determined (400000 m^2, which is 0.712% of the area of Suwon) with reference to the Roof Greening Promotion Plan of Seoul. Subsequently, roof greening types were classified into low, medium, and high management based on the cases of roof greening. We found that the increase in the habitat area of *Paridae* depended on the types of roof greening and construction building. The buildings with the highest efficiency of increasing the habitat area in Suwon City (an increase of 1197.5%) were all commercial buildings except for those with low management, while the buildings with the lowest efficiency (115%) were public buildings. The information on the increases in the habitat area of *Paridae* and the cost of roof greening per area (m^2) for the three types of building can be used to establish suitable green roofs that will promote urban biodiversity.

1. Introduction

More than half of the world's population lives in cities, urbanization is rapidly progressing, natural environments are being lost, and green areas are becoming insufficient, making it difficult for species to find appropriate habitats.(1) As a result, biodiversity in cities is decreasing. Recognizing this crisis worldwide, the Convention on Biological Diversity (CBD) proposed five strategic goals and 20 clear goals to be achieved by 2020 in the Aichi Biodiversity Targets.(2) On the basis of the results achieved by 2020, many countries have striven to achieve their goals by

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2022. Toward meeting the CBD's goals of reducing the rate of loss and fragmentation of green spaces and natural habitats, we selected roof greening as an approach for expanding green spaces and habitats in this study. Roof greening is attracting attention as an economical and efficient ecological restoration technology to increase biodiversity in cities. Various species using greened roofs in cities have been monitored, and the findings demonstrated roof greening to be a suitable means of achieving CBD's goal of connecting fragmented green areas.

The Republic of Korea has developed rapidly since the 1950s, and rapid urbanization is currently underway nationwide.(3) This has led to significant changes in land use and the environment.(4) Along with these changes, policies to secure green and habitat areas and increase biodiversity in cities are necessary to introduce economic and efficient greening in pre-developed cities.(5) However, owing to the limited budget of the national and local governments, it is not easy to purchase expensive urban sites and convert them into public green areas.

Therefore, a technology that introduces green areas with high cost efficiency to maintain and preserve biodiversity is attracting much attention. Typical technologies, such as roof greening, wall greening, lane gardening, and street greening, utilize small spaces in the city.(6) Roof greening can be created through a low-, medium-, or high-management approach, depending on the load and management level appropriate for existing buildings.(7) Green roofs can also provide a resting place for birds after a flight and a complementary habitat that supplies water.(8)

Cities in developed countries are encouraging the creation of green roofs. Portland in the United States provides a subsidy of \$54/m^2, while New York provides a one-year tax reduction of \$48/m^2. Toronto in Canada and Copenhagen in Denmark have made installation compulsory for some buildings. Additionally, citizens' interest in various support policies and the environment has been found to positively affect the expansion of rooftop greening systems and promote biodiversity.

Many studies have analyzed the effect of roof greening on promoting biodiversity.(9,10) In a previous study, a bird species was used as the target species, and grades were given to research buildings for their ecological characteristics and location as criteria for the species with the aim of improving the functionality of the green network in Jung-gu, Seoul.(11) Many previous studies selected a site for roof greening to connect green areas in non-urban zones and those in urban zones (core green and green base areas), anticipating economic benefits in the process.(12–15) However, one might ask what type of roof greening is effective for each type of building. Research on evaluating the quantitative effect of a plan according to the type of building (residential, commercial, or public building) is still insufficient.

Most of the previous studies focusing on urban biodiversity were limited to birds and considered the size of green areas in cities and citizens' preferences.(16–18) In particular, birds are suitable species for evaluating the health of urban ecosystems.(19) Because birds can fly and move across cities, they have fewer mobility restrictions than other animals.(20)

The purpose of this study is to analyze how the increased efficiency of the habitat of *Paridae*, a representative bird inhabiting the city, changes according to the urban rooftop greening scenario in Suwon, Korea, and to identify the most efficient rooftop greening plan. Suwon City plays a leading role in promoting biodiversity as it holds a regular biodiversity forum to raise citizens' interest and participates in creating biodiversity maps. It is crucial as a research destination because many of Suwon's citizens recognize biodiversity's importance.(21)

Paridae, commonly found nationwide in Korea, is a small bird of the order of sparrow and is a representative species that lives in Korean cities owing to its relatively abundant population. Vegetation cover and natural vegetation biomass at the city center are critical factors that determine the species diversity of urban algae. Suwon City, the subject of this study, also completed an individual survey of birds during the map production of the urban ecosystem's status in 2019, and among them, *Paridae* was identified as the most populous species in the city. As a result, it played a vital role in urban biodiversity and was selected as the target species of this study.(22)

This study aims to analyze the efficiency of various roof greening plans in Suwon City for increasing the *Paridae* population and to identify the most efficient roof greening plan. To this end, roof greening plans are developed and applied to different building types to compare the changes in the area of the habitat suitable for *Paridae* for each scenario. To analyze the efficiency of each scenario, the ratio of the increase in habitat area to that in roof greening area was calculated and the ratio of the increase in habitat area to that in roof greening cost was determined. The results of this study can be used as a scientific basis to support policymaking when establishing future roof greening and ecological restoration projects and promoting biodiversity in the city.

2. Methods

2.1 Scope of study

The spatial scope of this study is Suwon City, located in the inland region of southwest Gyeonggi-do with a latitude of 37.24°N and a longitude of 127.17°E. Suwon City has an area of 121.03 km^2, a population of 1185041, and a population density of 9790.92 people/km^2, making it one of the larger cities in Korea. In summer, Suwon City is hotter than the nearby cities of Incheon and Seoul, and it also has a large temperature difference between summer and winter. It generally has a gentle slope from the northeast to the southwest, with no high or steep mountains, and it has plains to the south (Fig. 1). The temporal scope of the study is 2019 considering the year of making maps of the urban ecosystem's status in Suwon where individual data can be utilized.

Potential target species of the study were birds that appeared in relatively large numbers in Suwon City. As a result of analyzing the appearance data of bird species in the 2019 Urban Ecosystem Status Map produced by Suwon City to select the target species, we found that a large number of birds appeared both at the center of Suwon City and outside it (Table 1; Fig. 2). Among them, *Paridae*, which had the largest number in Suwon City, was designated as the target species. The coordinates of *Paridae* appearances were used as a dependent variable.

The overall research process was as follows (Fig. 3). The input data used in the study consisted of the coordinates of *Paridae* appearing in Suwon, environmental variables related to *Paridae*, and roof greening plans expected to expand the range of the *Paridae* habitat. After selecting a statistical model based on the input data, the model was verified by producing and utilizing the dependent variable (*Paridae* coordinates), independent variables (environmental

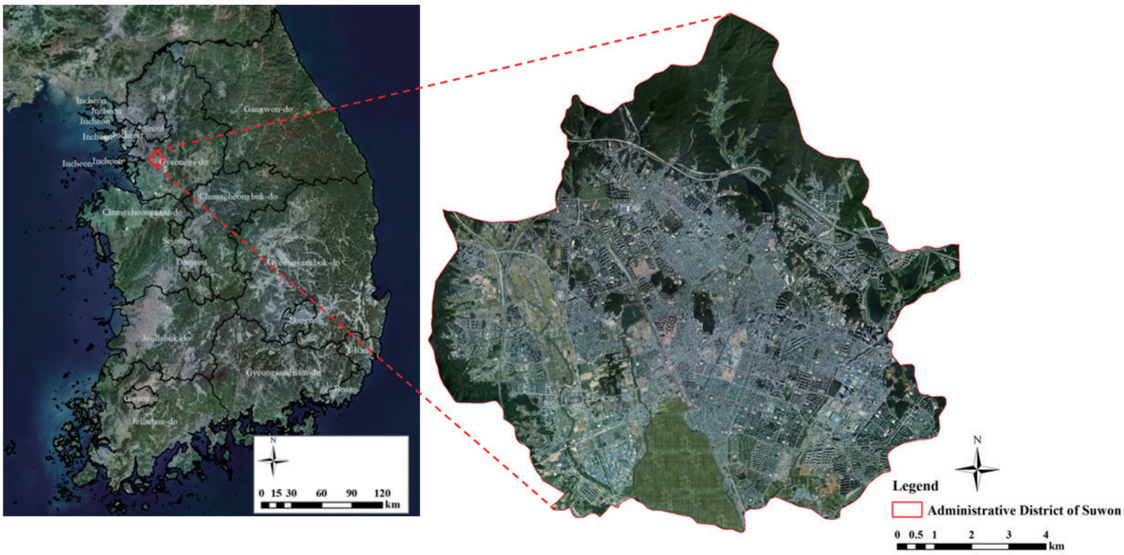


Fig. 1. (Color online) Study site.

Table 1
Occurrence data of *Paridae* in Suwon City.

Family	Species	Population
Paridae	*Parus minor*	93
	Periparus ater	4
	Poecile palustris	81
	Parus varius	23
Total		**201**

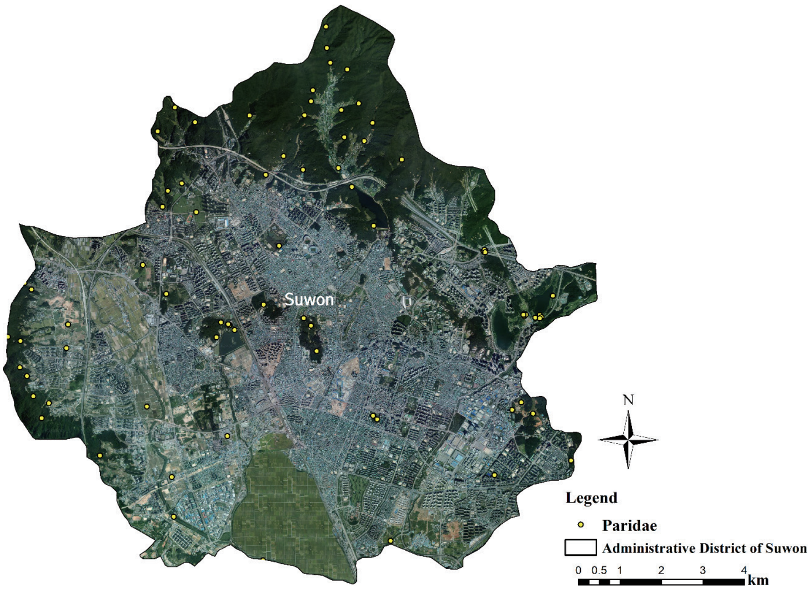


Fig. 2. (Color online) Locations of *Paridae* in Suwon.

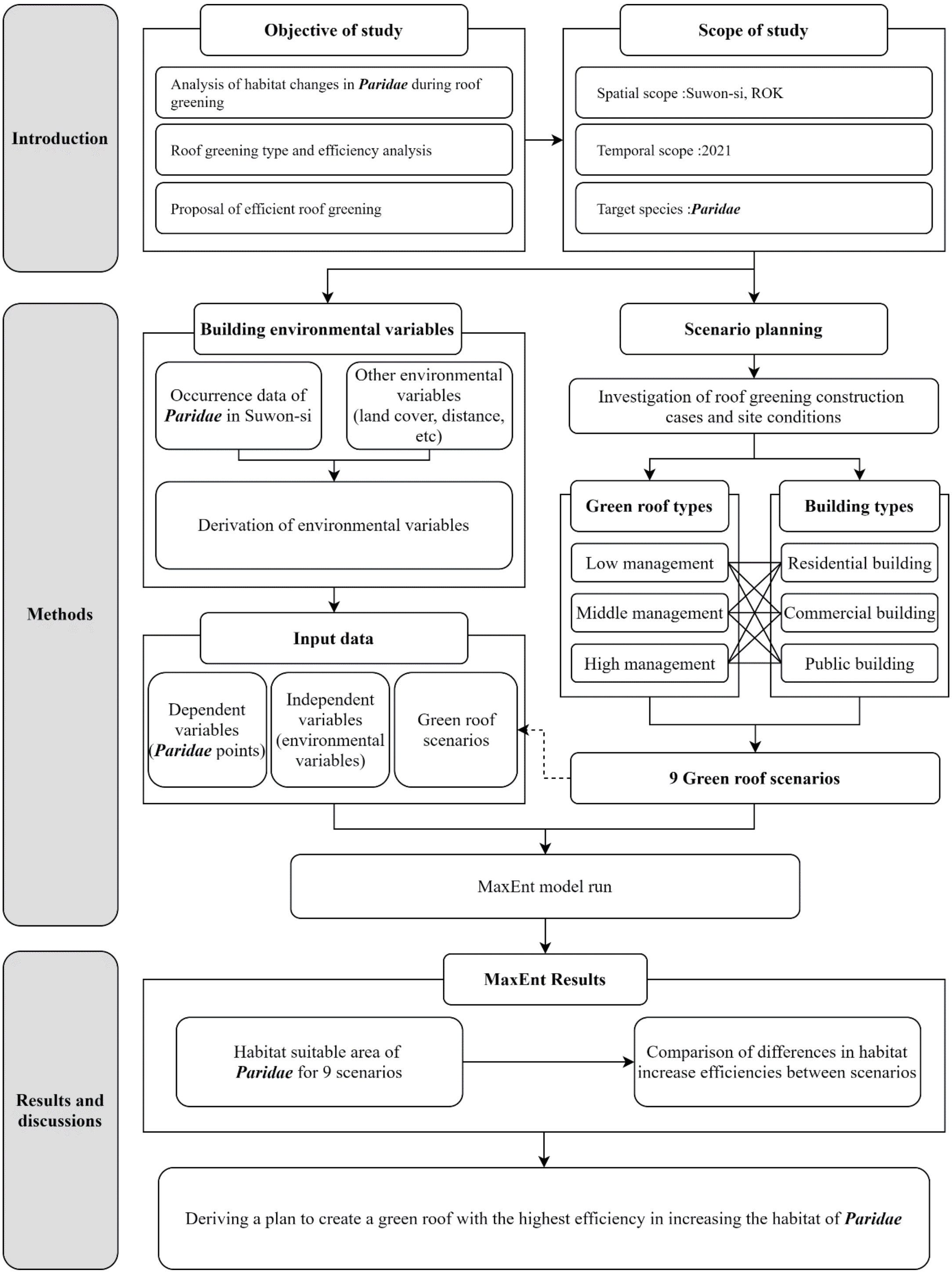


Fig. 3. Research flow chart.

variables), and roof greening plans. Based on verification results, the effect of expanding the habitat was confirmed by comparing the current habitat of *Paridae* before and after constructing green roofs for each scenario and deriving the efficiency of each roof greening plan (Fig. 3).

2.2 Environmental variable data

To select environmental variables to evaluate the habitat suitability for *Paridae*, we considered the environmental variables used in the analysis of the habitat suitability for birds in previous studies, such as the amounts of green space and cultivated land, climate, and topography. We selected 10 environmental variables that were highly correlated with *Paridae* (Table 2).

The first variable, the land cover, was used as a categorical environmental variable for land use and as a variable to analyze the location preference of *Paridae* according to land use. Environmental variables 2 to 6 are variables that are highly related to human disturbance. Variables 7 to 9 are land-use variables in the natural environment that are used to analyze *Paridae*'s natural growth process and pattern.(23–25) All environmental variables were produced with a high resolution of 5 m × 5 m (Table 2). All environmental variables were edited and created using ESRI's ArcGIS 10.4.1.

2.3 Species distribution model

Owing to its reliability demonstrated in several previous studies, we used the Maxent 3.4.4 model (Maxent) to predict the species distribution using the species appearance data of the target species.(26–29) This model is a nonlinear and statistical distribution model that predicts the distribution of living creatures from the appearance data and environmental factors. This machine learning model can be helpful when data such as species appearance and non-appearance are minimal or when ordinary statistical inference methods cannot be used to derive a probability distribution.(30) It predicts the species distribution using the theory of maximum entropy,(31) i.e., the species distribution when the degree of disorder is maximum.(32)

Although it is possible to obtain the appearance and non-appearance coordinates for species that have been closely investigated, it is difficult to generate non-appearance coordinates for most species.(33) Because non-appearance information could not be obtained for *Paridae* in Suwon City, Maxent was applied in this study. In addition, Maxent is effective for applying various models and deriving optimal results by manipulating data and applying environmental

Table 2
Environmental variables.

No.	Abbreviation	Type	Variable
1	lc_type	Categorical	Land cover (seven types)
2	dist_resi	Continuous	Distance from residential area
3	dist_indus	Continuous	Distance from industrial facility area
4	dist_public	Continuous	Distance from public facility area/reflect recovery technology
5	dist_comm	Continuous	Distance from commercial area/reflect recovery technology
6	dist_road	Continuous	Distance from road
7	dist_green	Continuous	Distance from green
8	dist_forest	Continuous	Distance from forest
9	dist_river	Continuous	Distance from river
10	dist field	Continuous	Distance from field

(Source: Land Environment Geospatial Information, 2019) variables. The statistical interpretation of variables is possible by considering the contribution of each variable.(34)

2.4 Developing a green roof scenario

To verify the assumption that the expansion of the suitable habitat area will depend on the type of building subject to roof greening and the area of roof greening, we developed a roof greening plan that can be applied to the species distribution model. There are five main steps in developing a roof greening plan.

The first step is to select a target space where roof greening could be applied. Roof greening refers to forming a green space on the roof of a building (here we consider residential, commercial, and industrial buildings), where plants can be planted, can grow, or can be given water space.(35) To classify the type of building to which roof greening is applied, we employed land-use criteria based on the Korean legal system. We considered that the effect of a green roof differed for each area of use and that the findings of our study would be helpful for policymaking by decision-makers. We selected three types of building where roof greening can be applied: public, commercial, and residential. School buildings can be used as a template for public buildings, with rooftop greening also used for education to highlight the importance of urban ecosystems. Commercial buildings can use rooftop greening to attract commerce through improved landscaping. The roofs of these three building types were identified as urban spaces where green roofs could be created, considering the size of buildings, the characteristics of users, and the support policies of the local government.

The second step is to calculate the roof area allocated to greening for each type of building. We referred to the Roof Greening Promotion Plan of Seoul to calculate the appropriate roof greening area.(37) The Seoul Metropolitan Government has established and is implementing a mid-to-long-term plan to expand the green roof area. In the plan for Seoul, the target area is 0.712% of the total area of the city. We set the same target area for Suwon City.

The third step is to distinguish between types of roof greening. In Korea, roof greening is divided into three types in consideration of the conditions and budgets of buildings, namely, low, medium, and high management. Low management, also called the lightweight type, mainly involves the growth of zippy plants with minimal irrigation, mowing, fertilizer, and so forth, and generally uses lightweight artificial soil. This type of roof greening is mainly applied to the roofs of buildings with structural restrictions or complicated maintenance. Medium management, also called the mixed type, uses soil with a depth of about 10 to 30 cm, focuses on ground bark plants and short shrubs, and aims for minimal management. High management, also called the heavy type, involves building a greening system that presupposes active use and management and consists of multilayered planting using ground cover plants, shrubs, and trees. Therefore, management practices such as irrigation, fertilization, and pruning are essential in meeting the needs of users. High-management roof greening can be applied when the building has no structural problems.

The fourth step is to change the target buildings to green areas similar to the rooftop greening type so that the roof greening creation scenario can be applied to the species distribution model.

Among the target building types, public, commercial, and residential, a rooftop area of 400,000 m², or 0.712% of the building in Suwon-si, was selected as the roof greening area. Large-area buildings were prioritized when selecting buildings by type. High-rise buildings such as apartments were excluded from the selection process because the largest possible habitat was formed to help the habitation of animals and plants in the city, including *Paridae*, and realistic conditions for creating green roofs were chosen. For each type of building, one of the three types of roof greening (low, medium, and high management) was selected. By projecting the manufactured environmental variables into the previously developed model in Maxent, it is possible to determine the change in the distribution of habitat sites when roof greening is performed with the existing habitat environment. In this manner, by applying different types of building and roof greening according to the scenario, changes in the habitat of *Paridae* in various scenarios were analyzed and the effects were compared.

The final step of the study is to calculate the percentage of habitat increase according to the increase in green roof area. The cost of each type of roof greening created in Korea was investigated to analyze economic efficiency, and the area where the habitat was expanded for the cost used for composition was analyzed. As a result of investigating the average cost of construction by the type of roof greening, it was found that 250000–300000 won for low management (lightweight type) per 1 m^2, 500000–600000 won for medium management (mixed type), and 600000–1000000 won for high management (weight type) were needed.(38,39) This study applied three types of roof greening composition cost: minimum, average, and maximum. The construction cost was calculated as 400000 m^2, with low management having a minimum of 100 billion won, an average of 110 billion won, and a maximum of 120 billion won; medium management having a minimum of 200 billion won, an average of 220 billion won, and a maximum of 240 billion won; and high management having a minimum of 240 billion won, an average of 320 billion won, and a maximum of 400 billion won.

3. Results

3.1 Analysis result of suitable area for *Paridae* habitat

As a result of analyzing the habitat suitable for *Paridae*, a large-scale habitat was found to concentrate in the northeast and southwest of Suwon City, and the habitat was distributed around some green areas at the center of the city (Fig. 4). The habitat in the northeast and southwest mainly consists of large-scale green patches (forest), and the habitat at the center of the city has been identified as dark green.

As a result of driving the model reflecting the roof greening plan, the reliability of the model was 0.881 for the area under curve (AUC) value derived through the Receiver Operating Characteristic (ROC) curve analysis, showing a meaningful reliability value. In general, studies using statistical models are evaluated to be excellent when the AUC value is 0.9–1.0, good when it is 0.8–0.89, fixed when it is 0.7–0.79, and inadequate when it is 0.51–0.69.(40) The logistic output result, which shows the estimated probability of species appearing as a value between 0 and 1, was selected, and the threshold value to be used as the standard for species appearing in

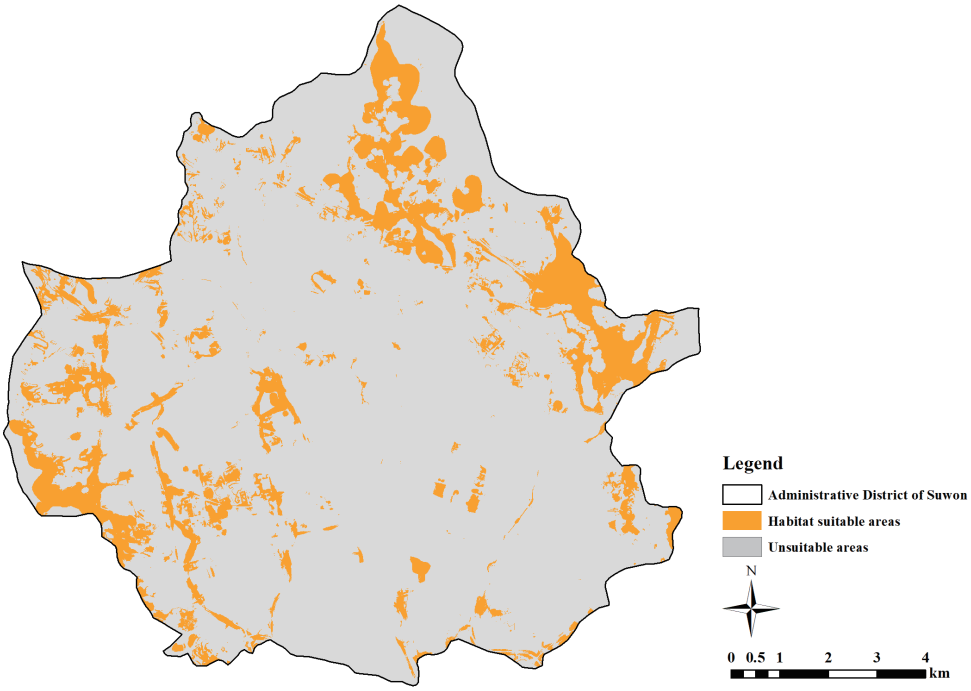


Fig. 4. (Color online) Suitable habitat area of *Paridae*.

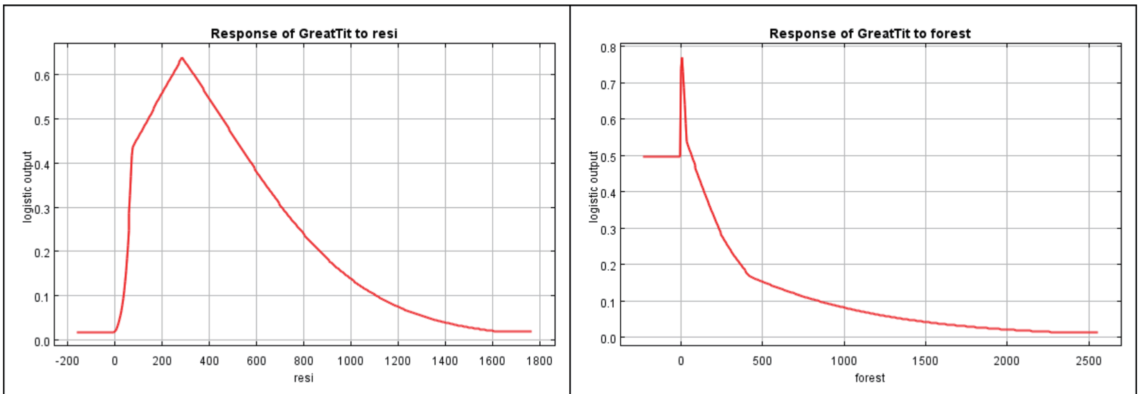
the habitat probability map to determine the suitable habitat area was 0.296. Among the environmental variables before roof greening was reflected, the highest contribution was shown in the order of distance from residential buildings, distance from forests, and distance from fields (Table 3). Looking at the reaction curve, the reaction curve patterns of residential, public, and commercial buildings were similar. The probability of the appearance of *Paridae* increased from 0 to 350 m, and the farther the distance after 350 m, the lower the probability of appearance. Therefore, when roof greening is applied to residential, public, and commercial buildings, a habitat is expected to improve significantly (Fig. 5).

3.2 Scenario development

As a result of developing the scenario in which to apply the roof greening plan to buildings by type, a total of nine scenarios were derived by applying low-, medium-, and high-management roof greening to three types of building (residential, public, and commercial). For the detailed results of Maxent-applied rooftop greening scenarios by type, the characteristics of broad-leaved forests closely related to the growth of *Paridae* living in Suwon were applied among the classifications existing in the land cover classification in the case of high-management roof greening. In the case of medium-management roof greening, the appearance point of *Paridae* is relatively smaller than that in broad-leaved forests, and the characteristics of grassland with poor function as a habitat were applied. In the case of low-management roof greening, the property of the field, which had the least appearance point of *Paridae* and relatively the least function as a habitat, was considered (Fig. 3).

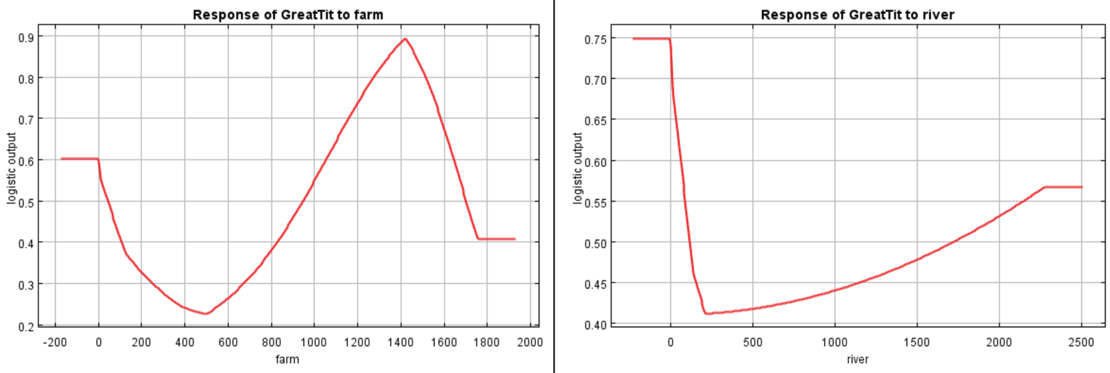
Table 3
Contributions of environmental variables.

Variable	Contribution
Distance from residential area	0.352
Distance from forest	0.234
Distance from field	0.166
Distance from river	0.090
Land cover (7 types)	0.072
Distance from industrial facility area	0.025
Distance from public facility area	0.018
Distance from road	0.018
Distance from commercial area	0.017
Distance from green	0.008



1. Distance from residential area

2. Distance from forest



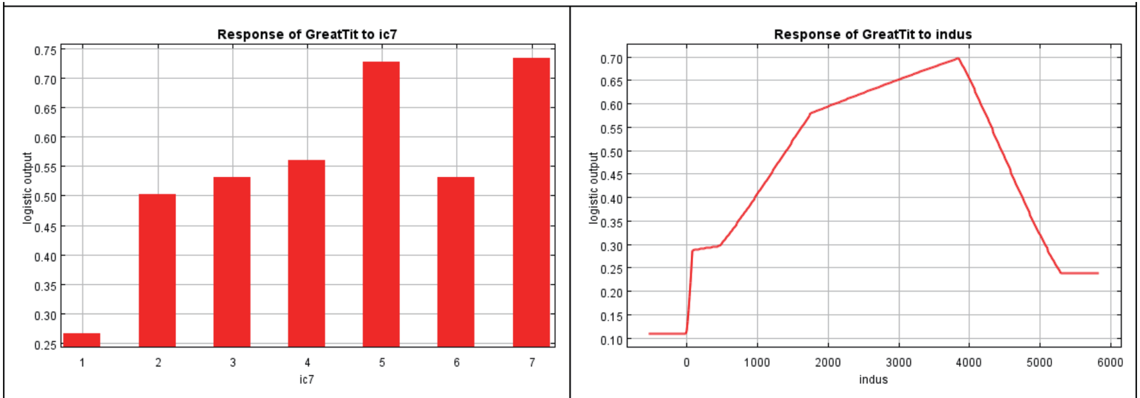
3. Distance from farm

4. Distance from river

Fig. 5. (Color online) Response curve graphs of environmental variables. (1, 2, 3, 4, 6, 7, 8, 9, 10): *y* = probability of presence, *x* = distance (m), (5) *y* = probability of presence, *x* = land cover (7 types: 1. urbanization area, 2. agricultural area, 3. forest, 4. grassland, 5. wetland, 6. bare land, 7. river).

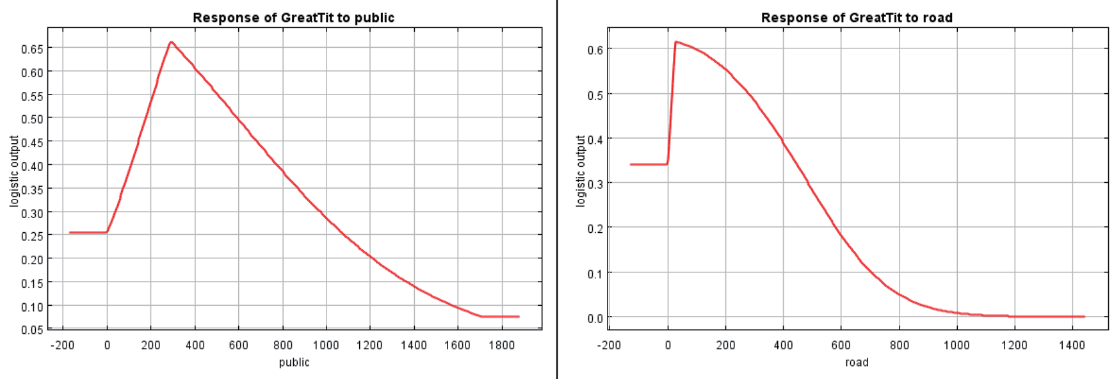
3.3 Change in habitat suitability according to green roof scenarios

If one looks at the map of the status of each user, which will serve as a green connection (roof greening) linking the green areas of Suwon City, one can see that residential buildings are evenly



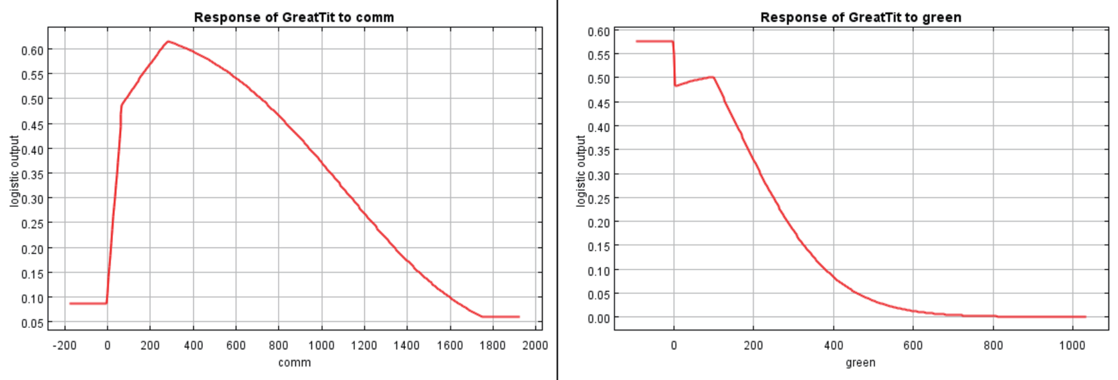
5. Land cover (7 types)

6. Distance from industrial facility area



7. Distance from public facility area

8. Distance from road



9. Distance from commercial area

10. Distance from green

Fig. 5. (Color online) (Continued).

distributed throughout Suwon City. In the case of public buildings, they are indeed distributed throughout the city, but their number is relatively smaller than that of residential buildings. In the case of commercial buildings, it is possible to examine whether their distribution is similar to that of residential buildings (Fig. 6).

In the case of the low-management roof greening of residential buildings, the area of the habitat increased by 550000 m^2, and the ratio of increase to the area reflected in roof greening

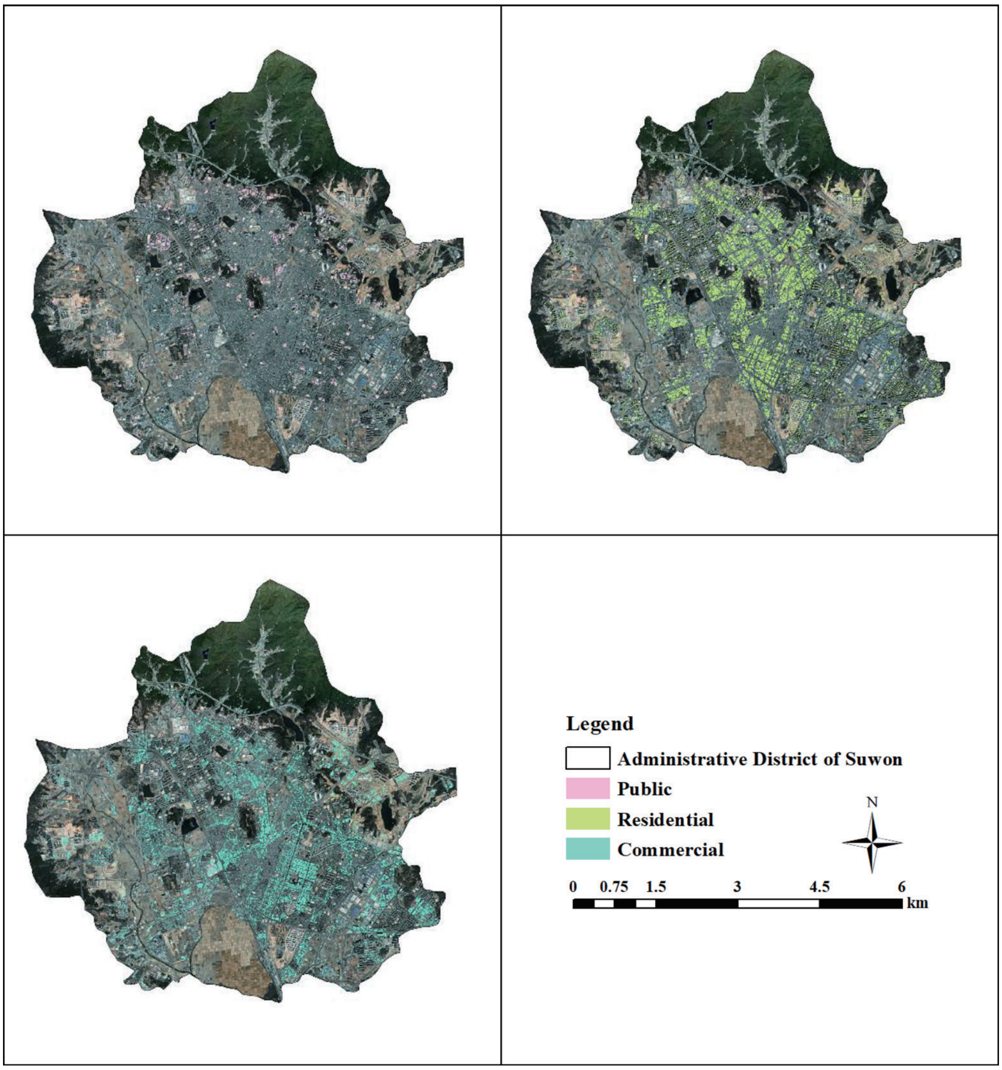


Fig. 6. (Color online) Three types of spatial area for green roof.

was 137.5%. In the case of medium-management roof greening, the area of the habitat increased by 1910000 m^2 at a rate of 477.5%. For high-management roof greening, the area of the habitat increased by 2830000 m^2 at a rate of 707.5%. In the case of residential buildings, the rate of increase in habitat area was high in the order of high, medium, and low management (Fig. 7).

In the case of low-management roof greening of commercial buildings, the habitat area increased by 500000 m^2, and the ratio of increase to the reflected roof greening area was 125%. In the case of medium-management roof greening, the habitat area increased by 4000000 m^2 at a rate of 1000%. In the case of high-management roof greening, the habitat thanks to the correction area increased by 4790000 m^2 at a rate of 1197.5%. For commercial buildings, the growth rate of habitat sites was high in the order of high, medium, and low-management roof greening (Fig. 8).

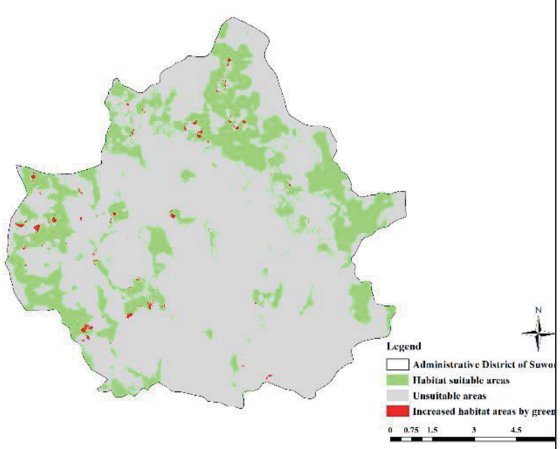
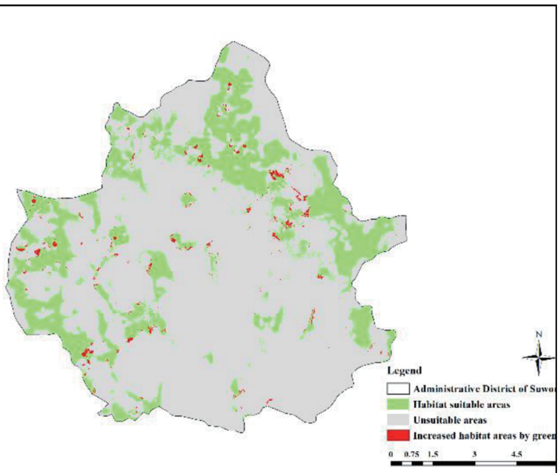
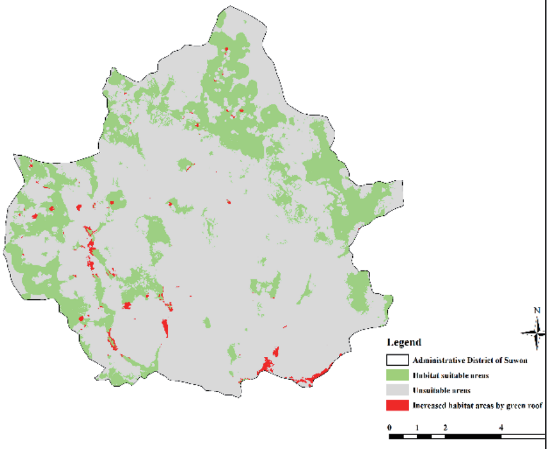
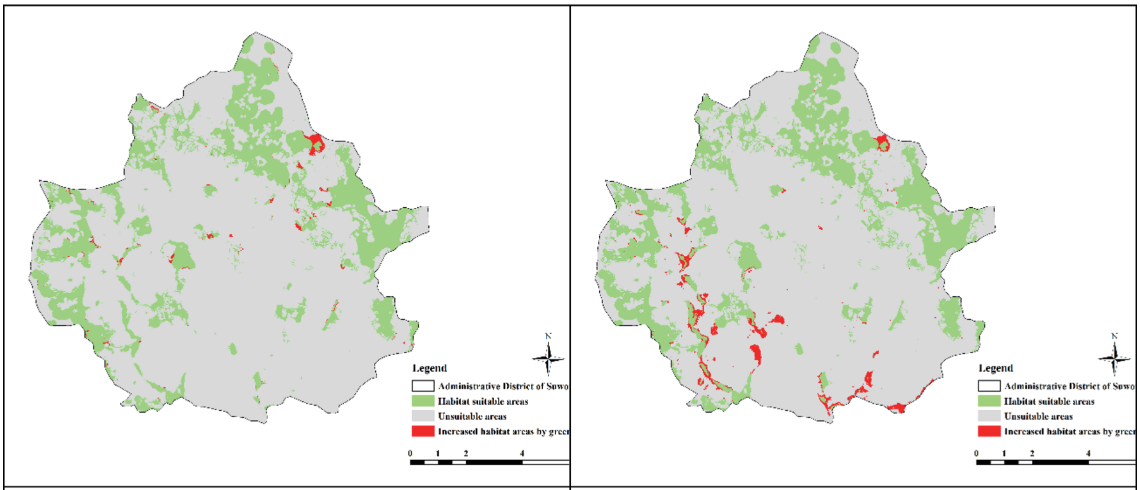
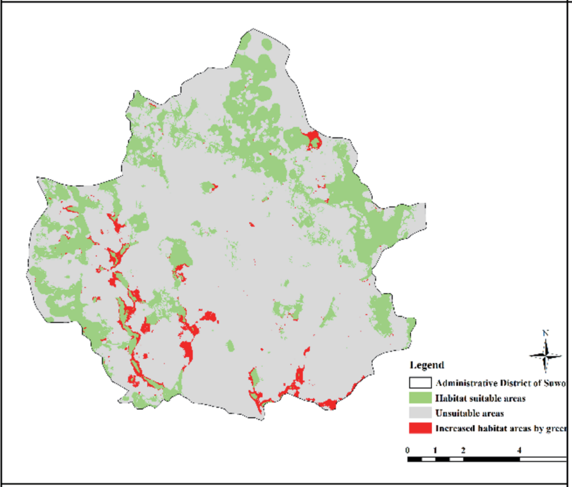
	
Low management	Medium management
Increased area: 550000 m^2 Rate of increase: 137.5%	Increased area: 1910000 m^2 Rate of increase: 477.5%
	
High management	
Increased area: 2830000 m^2 Rate of increase: 707.5%	

Fig. 7. (Color online) Application result of green roof plan in residential building.

In the case of low-management roof greening of public buildings, the number of habitats increased by 1090000 m^2, and the ratio of habitat growth to the greening area on the roof was 272.5%. In the case of medium-management roof greening, the number of habitats increased by 460000 m^2 at a rate of 115%, and in the case of high-management roof greening, it increased by 2700000 m^2 at a rate of 575%. For public buildings, the rate of increase in the number of habitats was high in the order of high, low, and medium management (Fig. 9).



Low management	Medium management
Increased area: 500000 m^2 Rate of increase: 125%	Increased area: 4000000 m^2 Rate of increase: 1000%



High management

Increased area: 4790000 m^2

Rate of increase: 1197.5%

Fig. 8. (Color online) Application result of roof greening plan in commercial building.

When the three types of roof greening were applied to the three types of building, the results showed that the number of habitats gradually increased in the order of low, medium, and high management except for public buildings where roof greening was created for residential, commercial, and public buildings. In the case of middle and high management, the highest increase value was found in commercial buildings, and in the case of low management, the highest increase value was found in public buildings. These results are summarized in Table 4.

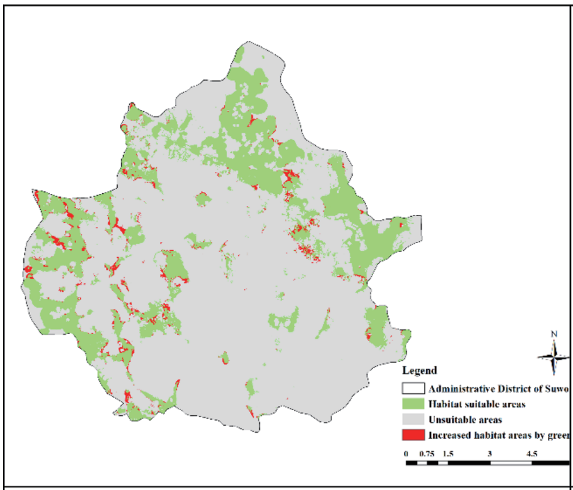
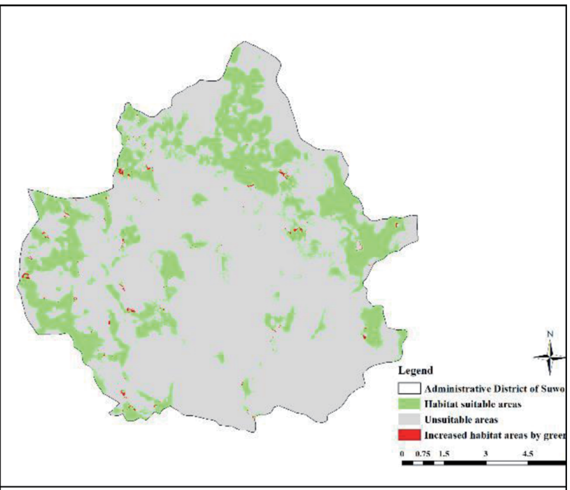
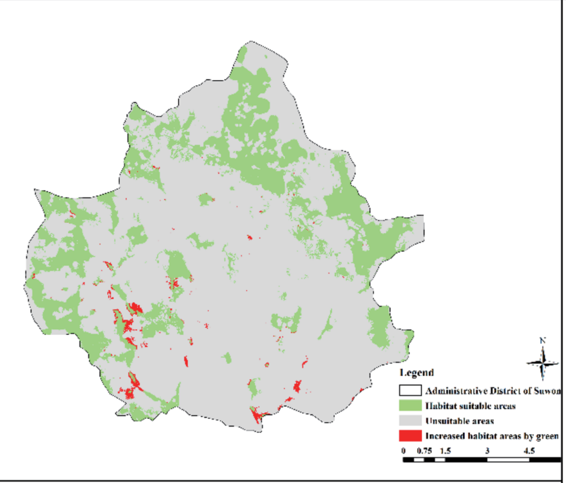
	
Low management	Medium management
Increased area: 1090000 m^2 Rate of increase: 272.5%	Increased area: 460000 m^2 Rate of increase: 115%
	
High management	
Increased area: 2700000 m^2 Rate of increase: 575%	

Fig. 9. (Color online) Application result of roof greening plan in public building.

3.4 Construction cost according to the type of roof greening

The increase in habitat area (m^2) derived by type was divided by 10000 won based on the cost of building a roof garden, and the cost was converted to how much it would cost per 1 m^2 of increased habitat. Considering the uncertainty of the average, the minimum, average, and maximum values were calculated for each type of roof greening (Table 5). As a result of

Table 4
Efficiency of green roof for each target area.

Target area of green roof			Scenario		
			Low management	Medium management	High management
Residential building	Quantitative increase efficiency of habitat	Area of increased habitat (m^2)	550000	1910000	2830000
		Rate of increased habitat compared with existing habitat (%)	137.5	477.5	707.5
Commercial building	Quantitative increase efficiency of habitat	Area of increased habitat (m^2)	500000	4000000	4790000
		Rate of increased habitat compared with existing habitat (%)	125.0	1000.0	1197.5
Public building	Quantitative increase efficiency of habitat	Area of increased habitat (m^2)	1090000	460000	2700000
		Rate of increased habitat compared with existing habitat (%)	272.5	115.0	575.0

Table 5
Economic efficiencies of suitable habitat areas of *Paridae* according to roof greening plan and building type.

Building type			Roof greening method		
			Low management	Medium management	High management
Residential building	Cost of roof greening	Minimum value	18.1	10.4	8.4
		Average value	20	11.5	11.3
		Maximum value	21.8	12.5	14.1
Commercial building	Cost of roof greening	Minimum value	20	5	5
		Average value	22	5.5	6.6
		Maximum value	24	6	8.3
Public building	Cost of roof greening	Minimum value	9.1	43.4	8.8
		Average value	10	47.8	11.8
		Maximum value	11	52.1	14.8

(Unit: 10000 won/m^2)

analyzing the economic efficiency of increasing the habitat area in residential buildings, the cost of roof greening per 1 m^2 of the increased habitat (10000 won) is summarized in the order of low, medium, and high management based on the average, with values of 20/11.5/11.3 being derived. When examining the average of commercial buildings, costs of 22/5.5/6.6 were derived in the order of low, medium, and high management. When looking at the average of public buildings, costs of 10/47.8/11.8 were derived in the order of low, medium, and high management.

4. Discussion

4.1 Characteristics of *Paridae* in Suwon City compared with previous studies on habitat characteristics of *Paridae*

Through previous studies, it was confirmed that birds performed three major activities in the roof greening space. However, these activities are based on the behavior of birds caused by complex factors.(41) If one thinks about the habitat environment of birds, one can think of other vital factors in the bird habitat, as well as roof greening. For example, there are buildings of various heights and artificial habitats, and if these environmental variables are collected and edited, it is believed that a roof greening plan with a higher rate of increase in habitat area can be created.

Studies on *Paridae* and roof greening have been verified through monitoring rather than analyzing the habitat. By monitoring, *Paridae*'s general right of action and ecological characteristics were determined to be, on average, a horizontal radius of 250 to 500 m and a vertical travel distance of 6 to 30 m.(16) The response curve of this study was analyzed, and the habitat probability significantly increased from 0 to 350 m. As the distance further increased from 350 m, the probability of the appearance of *Paridae* gradually decreased, which was found to be similar to the right of action of *Paridae*. In previous studies, *Paridae* frequently appeared in parks, fields, and grasslands in the city.(42–45) In this study, when roof greening by type was reflected, habitat increased adjacent to forests, grasslands, and farmlands (Fig. 10). When low-management roof greening was applied to commercial buildings, the ratio of habitat area increase was low, but the habitat area increased around cultivated lands (Fig. 11).

According to the results of monitoring in previous studies, bird excrement was observed in the green roof space, confirming that the roof greening space was used.(46) However, studies related to the ecological role of roof greening and its contribution to the promotion of biodiversity were insufficient compared with those on reducing environmental damage in cities, saving energy, and providing green space. In the urban planning stage, efficient roof greening will be

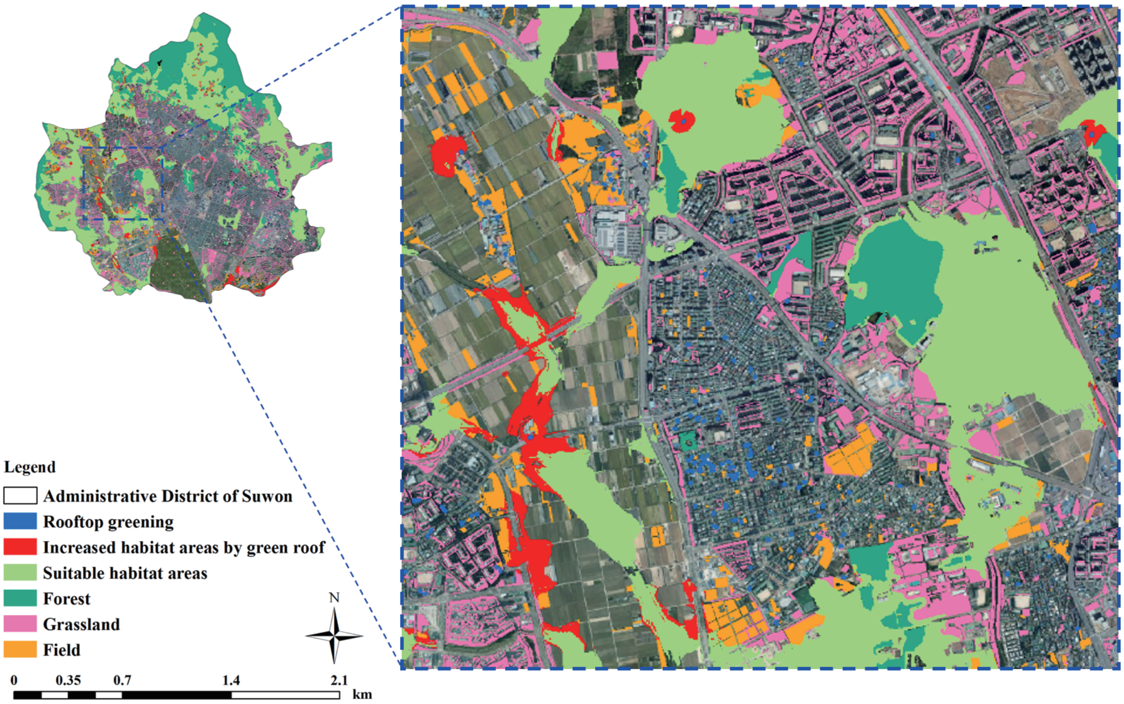


Fig. 10. (Color online) Study on expansion of habitat in residential buildings.

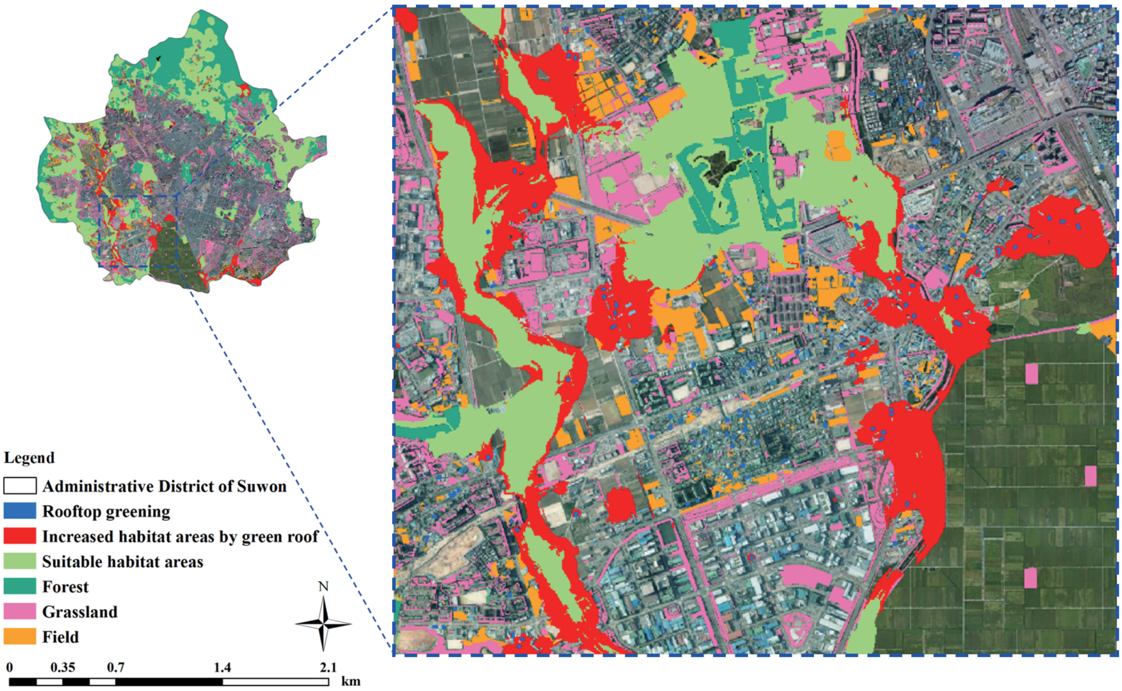


Fig. 11. (Color online) Overview of expansion of habitat in commercial buildings.

possible if habitat expansion for birds living in the city is spatially predicted on the basis of the roof greening plan.

Since this study only deals with roof greening, there is a limit to reflecting the scenario only in the area used, which is a building. In future studies, if many variables are added, such as securing green street areas on roads with high contributions and connectivity of natural green areas, the efficiency of roof greening could be higher and could be used as good reference and evidence. In future research, it is necessary to study how the application of technologies, such as the roof and wall greening of buildings and artificial habitats, affects and correlates with species living in cities.

4.2 Comparison of expected effect of green roof composition according to distribution characteristics of buildings by type

As a result of applying the roof greening plan for the three types of building—residential, commercial, and public—the increase in the habitat area of *Paridae* was different (Table 4). The reason is estimated to be the differences in the location characteristics of buildings by use and the area and distribution of surrounding green areas. Nevertheless, in the case of high-management roof greening, the rate of increase in habitat area in all-purpose buildings was the highest, so high management is judged to be the best type of roof greening to improve habitat suitability. However, a different tendency was also identified in the cases of middle and low management. In the case of low management, the highest rate of increase in habitat area was observed in public buildings, which is believed to have improved habitat compatibility even if only low-management roof gardening was applied because green areas were already formed well around public buildings.

An in-depth analysis of the characteristics of the results of the roof greening plan in each type of building shows that residential buildings are evenly distributed throughout Suwon, and the habitat area is increased around the fields and grasslands in the west of Suwon. This is because the environments of most residential buildings are rich in green areas because of improved landscaping, and the connection between green areas did not increase significantly, even when roof greening was created in residential buildings. For this reason, the habitat area did not increase around forests and grasslands but around fields (Fig. 10).

Second, when rooftop greening was created in commercial buildings, the rate of increase in the habitat area was relatively higher than those in the other areas used. An in-depth analysis of the cause of the high increase can confirm the distribution of commercial buildings similar to residential buildings in Suwon. However, it is difficult to judge habitat suitability as the only locational factor (Fig. 9). For example, if there are many roads with numerous vehicle movements in the area used, various factors such as the presence or absence of old buildings or parks and artificial green spaces in the vicinity, as well as access to rivers, affect habitat suitability. Owing to the location characteristics of commercial buildings, there are relatively few green areas around them compared with residential and public buildings. For this reason, various surrounding green spaces are formed when roof greening is established in a commercial building, the role of green spaces connecting green areas increases, and the rate of increase in the habitat area becomes significantly higher than that of the other areas used (Fig. 11).

Third, in the case of the low-management roof greening of public buildings, the habitat increase rate was the highest. Like residential buildings, there are as many landscaping areas in public buildings when examining the distribution and location characteristics. As a result, the formation of a green network is well established, and even if only low-management roof greening is applied, the suitability of the format increases (Table 4; Fig. 12).

4.3 Economic efficiency of suitable habitat areas of *Paridae* according to the roof greening plan and building type

In the case of residential buildings, among the types of roof greening (low, medium, and high management), high management had the highest rate of increase in habitat area in terms of economic aspects. It is judged that this result is due to the presence of grasslands and green areas in the vicinity due to the locational characteristics of residential buildings. In the case of commercial buildings, medium management showed the highest rate of increase in habitat from an economic point of view. In the case of a commercial building, there is no grassland or green area around it, unlike a residential building, owing to its location. These results were derived by increasing the role of connecting green areas with the medium-management roof greening composition and grassland properties. In the case of public buildings, low-management roof greening showed a high growth rate in habitat in terms of economic aspects. However, owing to the nature of public buildings, green areas are sufficiently formed similarly to the case of

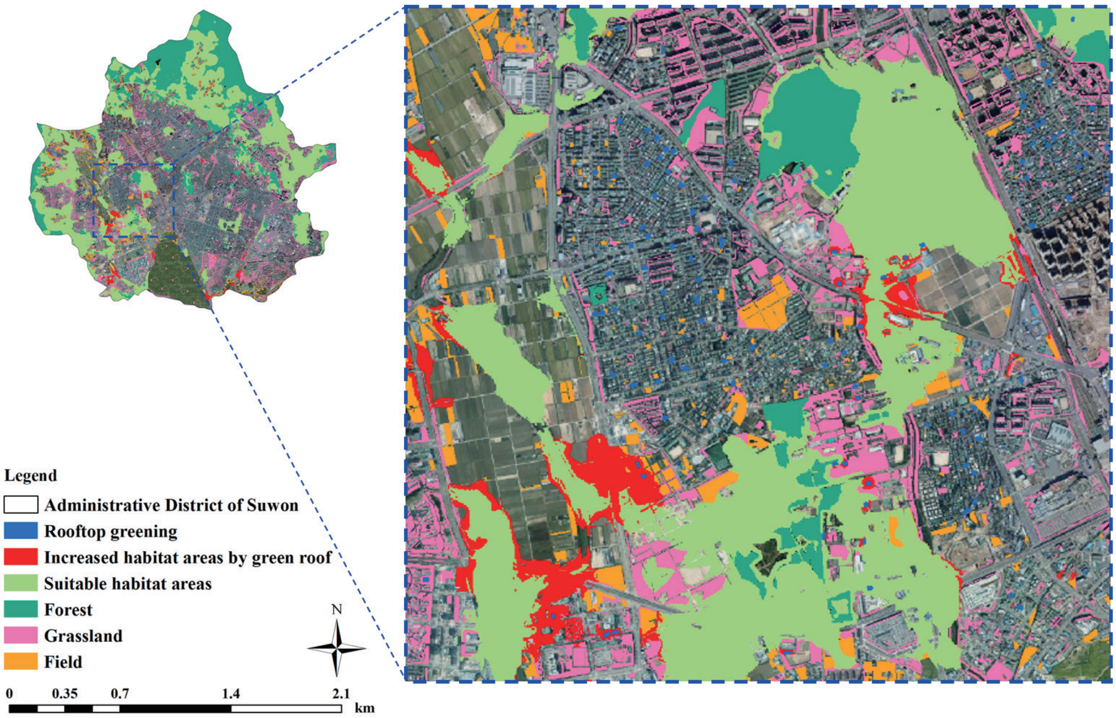


Fig. 12. (Color online) Study on expansion of habitat in public buildings.

residential buildings; thus, for this reason, the habitat will increase even if only low- management roof greening is created.

The resulting table of the increase in habitat area according to the roof greening composition and the increase in habitat area considering economic aspects was different for medium- and high-management roof greening. It is judged that this result is due to the considerable variation in the composition cost of the high-management roof gardening. In constructing roof greening, the results were derived from three classifications in terms of cost (Table 5). These results can be used as a reference for what type of roof greening will be created for each type of building to expand the potential habitat of birds living in cities, such as *Paridae*, the subject species of this study.

5. Conclusions

In this study, the habitat of *Paridae* in Suwon City was identified using the species distribution model. In addition, changes in habitats were examined when three types of roof greening were applied to buildings for various purposes, while the types of roof greening for each building that was effective in expanding habitats were identified. Buildings representing Suwon City were considered in selecting structures for residential, commercial, and industrial use, except for high-rise apartments. To calculate the area to be created, a scenario was developed and applied to create a green roof on the 400,000 m^2 roof area of the target building by converting the area in the Roof Greening Promotion Plan of Seoul into a ratio. As a result of applying the roof greening plan, the overall increase in habitat area was obtained, but the rate of increase in habitat area was different in the three types of building. When the roof greening area increased, the areas where the habitat area increased significantly were commercial, residential, and public buildings.

On the other hand, in the case of commercial buildings, the increase in habitat area was the highest. The result indicating that roof greening in the urban area derived in this study helps increase the area of the species' habitat is expected to be used as part of a methodology for improving biodiversity in the city. Since this study was performed by considering only the increased habitat area, various interpretations of the economic efficiency table obtained in this study can be made if the management cost and function of the type of roof gardening for each building used are also considered. In particular, when establishing a roof greening plan in Suwon City, the results of this study can be referred to as a scientific basis for prioritizing what type of roof gardening should be carried out first according to the use of the building. In addition, the relationship between *Paridae* and rooftop greening can be analyzed by constructing various environmental spatial information systems in the city using sensors such as satellite images in the future research and development direction. It is expected that quantitative research to promote biodiversity in cities will be active through developing various sensor technologies in the future.

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